Developing feedback: how children of different age contribute to a tutoring interaction with adults

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***Abstract*—Learning is a social and interactional endeavor, in which the learner generally receives support from his/her social environment [1]. In this process, the learner's feedback is important as it provides information about the learner's current understanding which, in turn, enables the tutor to adjust his/her presentation accordingly [2], [3]. Thus, through their feedback learners can actively shape the tutor's presentation - a resource which is highly valuable, if we aim at enabling robot systems to learn from a tutor in social interaction. But what kind of feedback should a robot produce and at which time? In this paper, we analyze the interaction between parents and their infants (8 to 30 months) in a tutoring scenario with regard to the feedback provided by the learner in three different age groups. Our combined qualitative and quantitative analysis reveals which features of the feedback change with the infant's progressing age and cognitive capabilities.**

I. Introduction

Learning is a social and interactional endeavor, in which the learner generally receives support from his/her social environment [1], [4]. Developmental research has demonstrated that - when talking or presenting new actions to their young infants - adults modify their speech and actions [5], [6]. More recent studies have begun to identify objective criteria for gestural modification parameters using computational methods [7], [8]. Other studies have suggested that such modifications scaffold children's acquisition of language and action [5], [9]. Experiments have been conducted which suggest that the infants prefer to look at child-directed rather than at adult-directed action presentations [10]. However, the *learner's* contribution to the modified behavior and the learning process has received only little attention.

From an interactional perspective, the learner's feedback is important as it provides information about the learner's current understanding which, in turn, enables the tutor to adjust his/her presentation accordingly [2]. It has been documented that, once the infant's communication tends to break down, caregivers sensitively adjust subsequent messages [11]. More recently, we have shown that - in a task involving the demonstration of how to stack a set of differently sized cups - the learner's gaze towards relevant objects is influenced by the tutor's hand trajectories and, at the same time, contributes to shaping these trajectories [3]. Thus, through their feedback learners can actively shape the tutor's presentation - a resource which is highly valuable, if we aim at enabling robot systems to learn within and from social interaction. But what kind of feedback should a robot produce in a tutoring situation and at which time?

Building on our previous analysis, which has considered only a small data-set of pre-lexical infants (8 to 11 months), in this paper, we will investigate the feedback provided by infants of different age groups - pre-lexical (8 to 11 months), early lexical (12 to 23 months), lexical (24 to 30 months) - to a parent's action presentation. Patterns and features in demonstration and feedback will in a first step be ascertained by means of hypotheses acquired from qualitative investigation derived from Conversation Analysis. These patterns will then be found with quantitative measurements assessing computationally the bilateral structure of the interaction from annotations and features in motion and on a verbal level.

II. Background

A. Tutoring Situations: Contingency and Feedback

Interactional research has revealed to which extent in authentic social interaction, the co-participants' actions are closely related to each other and contingently respond to and build upon each other in a fine-grained interactional loop [2], [12]. In this line, the recipient's verbal "back-chanelling" behavior has become an important research topic and, as a multimodal account, it has been shown how some speakers' talk emerges step by step with regard to their recipients' changing foci of attention [13]. In tutoring situations, we find similar effects: Not only is the infant's gaze towards relevant objects influenced by the tutor's hand trajectories, but also, at the same time, the infant's gaze pro-actively shapes these trajectories [3]. Thus, in social interaction, the learner appears to be able to directly influence the tutor's presentation.

This *interactional loop* is particularly interesting, if we attempt to develop robot systems that should learn within and from social interaction. If we managed to provide the robot with appropriate feedback strategies, it should be able to elicit the kind of *input* from its tutor that it needs for its best functioning. However, existing feedback models provided in social robotics and artificial agents mostly operate on the level of context-independent rules attempting for smooth turn-taking [14] and do not address the issue of displaying "understanding" of an action as it is crucial in a tutoring/learning scenario.

B. Child Development and Cognitive Abilities

The ways in which parents demonstrate actions to their infants are commonly related to children's cognitive abilities. The motivation here is that we can gain some insights into how people adapt their interaction to cognitive abilities of their partner and what feedback they make use of. We expect that infants - due to their different levels of (cognitive, verbal, motoric) development - might produce different kinds of feedback which display their current understanding of the demonstrated action. According to the Denver Developmental Scales [15] different behavior can be observed depending on the child's age:

- 8 to 11 months: The child looks at a face, smiles back, smiles spontaneously and reaches for objects beyond its reach. It follows with the eyes 180 degrees, reacts to a bell, turns towards speech, begins to utter the words "mom" and "dad" undirectedly and can sit without help.
- 12 to 23 months: A child reveals wishes, begins to say "mom" and "dad" directedly, begins to combine words and pours raisins out of a jar as demonstrated.
- 24 to 30 months: A child uses syntactic constructions and says first name and last name, it easily accepts to be seperated from its mother. Note that children begin to recognize colors only later, at the age of 30 to 36 months.

III. Data

Our analysis is based on video-recordings from the Bielefeld "Motionese corpus", in which 64 pairs of parents were asked to present a set of 10 manipulative tasks both to their infants and to another adult. During the task, a parent and the child were facing each other, sitting across a table. The situation was videotaped with two cameras [7], [8]. For the analysis presented here, we focus on parent-infant-interaction and on one specific task: stacking differently sized cups, in which the assumed action consists of sequentially picking up the green (a1), the yellow (a2), and the red (a3) cup and to place them into the blue one. Some parents performed the task differently and sequentially put the red (a3) cup into the yellow one, then put the yellow (a2) cup containing the red one into the green one and then stacked all three cups inside the green (a1) cup into the blue one. These subjects were also included in the analyses.

	Group 1	Group 2		Group 3
		Group 2a	Group 2b	
Development	prelexical	early lexical	early lexical	lexical
Age in months	8 – 11	12 – 17	18 – 24	25 – 30
Number of Parents	22	11	13	18
Gender of Parents	10m, 12f	6m, 4f	6m, 7f	9m, 9f

TABLE I
THE SUBJECTS OF THE 3 DIFFERENT AGE GROUPS.

See table I for an overview of the subjects we considered. Group 2 was divided into two subgroups, because around 18 months, there is a drastic increase in the children's vocabulary from which children in age group 2b benefit, whereas in age group 2a, children usually only use one-word utterances.

IV. Methods

As human interactional behavior in natural interaction is highly complex and variable, we draw upon a combined qualitative and quantitative, manual and computational analysis to investigate the infants' feedback.

In a *first* step, we begin with a manual, qualitative analysis of the video-recordings in order to understand the interactional organization and the practical problems participants are solving in and through their actions. We use Conversation Analysis as a methodology, which allows us to investigate multimodal conduct in fine detail and opens the perspective on the question of how one participant's conduct is step by step influenced by and at the same time influences his/her co-participant's behavior. This first step (a) provides us with an understanding of the sequential organization and allows us to (b) reveal communicative patterns and (c) derive relevant features of the interactional organization, which we use - in a later step - as hypotheses to be investigated with quantitative methods on the entire data set.

Based on the qualitative analysis, we have - in a *second* step - undertaken systematic annotation of the entire corpus. Derived from step 1, several coders systematically and objectively annotated the following features, which are independent of content or theory and allow to attach precise timestamps to interactional events. We used time-based annotation tools (ELAN, PRAAT) and coders verified each other's work.

- For the infant:
  - gaze: annotated moving gaze towards a position, possible eye gaze directions: all objects in scene, interaction partner's face and hands, the experimenter. No annotation in case of occasional occlusion of infant's face.
  - speech
  - pointing and reaching gestures: marked in three phases: preparation phase, peak phase, retraction phase.
  - smiles
- For the adult:
  - speech
  - action: The beginning and ending of actions and subactions were annotated as in [8], see figure 1. Subactions corresponding to the transportation of the cups: a1, a2, a3.

While the use of two annotation tools allows us - in the laborious process of annotation - to use certain features for precision and support in the location of events on the timeline, we have to integrate their different XML-based data structures for subsequent analysis.

In a *third* step, the generated hypotheses are investigated computationally on the basis of the annotations. For this, timestamps and annotation values are parsed from the transcripts and loaded into MATLAB for further processing.

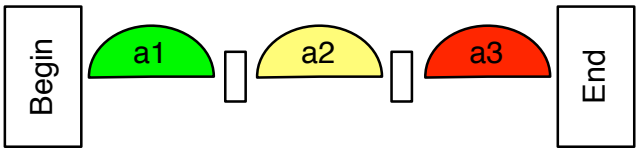

Fig. 1. Image showing the course of the demonstration. a1, a2, and a3 mark the transportations of the three cups.

V. Infant's Feedback

As expected from the interactional literature, our analyses of the "stacking cups"-data revealed that the co-participants' actions are closely related to each other and respond to and build upon each other in a very fine-grained interactional loop: The infants' feedback is intertwined with the ways in which parents present the action [3]. Thus, in what follows, we will firstly present the basic structure of the parents' action presentation, which serves as a baseline with regard to which we need to then locate the infants' feedback.

A. Parents' Action Presentation

In their basic version, the parents' presentation of how to stack the differently sized cups consists of (i) marking the beginning, (ii) the three movements of transporting cups separated by short pauses (a1, a2, a3) and (iii) marking the end of the action. When carrying out these action demonstrations, parents use both verbal language and bodily actions, such as gesture, gaze, facial expressions, manipulation of objects etc. Our analysis reveals, that the infant's feedback operates both on the level of continuous involvement (e.g. through gaze) and at specific places within the structure of the interaction (e.g. through pointing gestures).

B. Group 1: Prelexical Infants (8 to 11 months)

1) Qualitative Analysis: Parents presenting the action to their prelexical infants can be seen - to a large extent - to deal with the practical problem of helping the infant visually orient to relevant features of the scene: Infants appear to often look "somewhere" (i.e. unmotivated with regard to the task), and parents explicitly call for the infant's attention either verbally (name + look here) or by extended hand/arm movements [8]. If we consider more closely these interactions with regard to the infants' feedback, we find that they indeed respond to these cues offered by the parents by re-orienting their gaze to specific places at specific moments in time. The following interaction fragment shows such typical "attention grabbing"-patterns:

(i) Before the adult (VP: Versuchsperson/participant) begins to demonstrate the action, the infant (RC: recipient) gazes to the experimenter (figure 2, img.1). Once VP lifts his left hand to touch the blue cup (figure 2, img.2), RC immediately shifts his gaze to the hand/blue cup (figure 2, img.3).

(ii) VP then releases the blue cup and grabs the green cup instead, lifts it and explicitly calls for the infants' attention "LOOK" (figure 2, l.01, img.4). Again the child responds by re-orienting his gaze to the green cup (figure 2, img.5) and

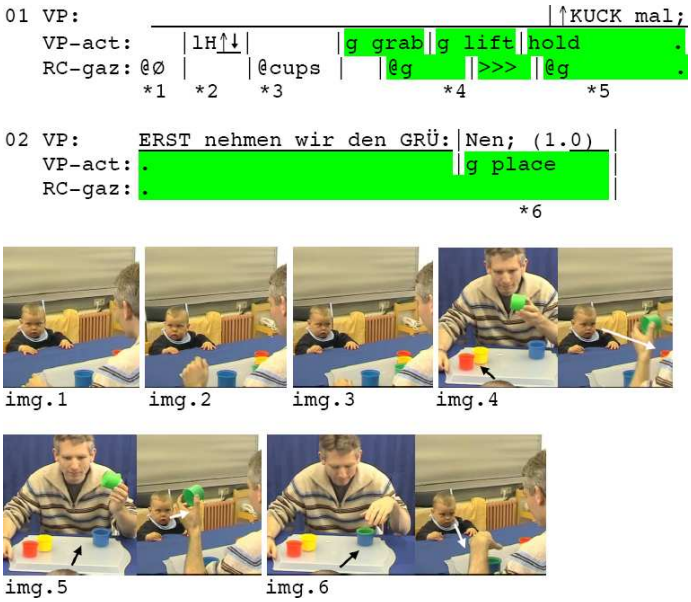

Fig. 2.

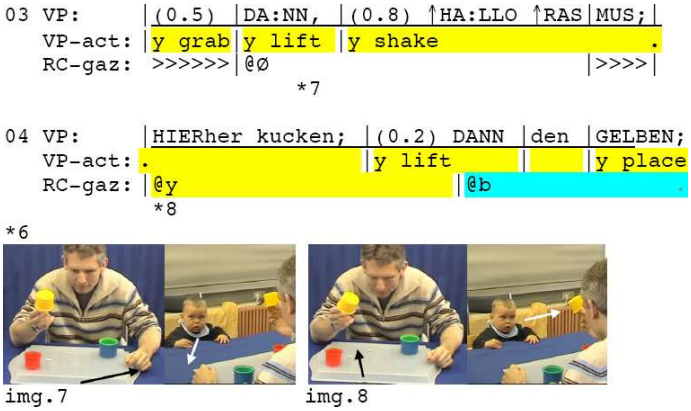

Fig. 3.

continuously following its trajectory with a short delay until VP drops it into the blue cup (figure 2, img.6).

(iii) VP then makes a 1.0 seconds pause both in motion and speech (figure 2, l.01), and the infant's attention again shifts to the side (figure 3, img.7). To start the second sub-action, VP grabs and lifts the next (yellow) cup, shakes it and calls "HE:LLO <name> LOOK here", which again, triggers the infant to reorient to the cup (figure 3, img.8).

At the same time, the infant in our example can be seen to be a silent observer of the action and also his other body motions (accept adjusting gaze direction) appear to "freeze" during the presentation.

These observations suggest that, in age group 1, the infants' feedback primarily consists of gazing behavior. As the analysis reveals, it matters to the participants that the infant gazes at the appropriate place at a given moment. Its precise timing in relationship to the adult's actions thus is important. Verbal utterances and other bodily behavior, however, seem to play only a marginal role.

2) Quantitative Analysis: As a very first step, to underline the importance of gaze as feedback, we counted the number of subjects, who give other active feedback in terms of verbalization, pointing or reaching gestures and smiling during the demonstrated action, see Figure 1 and found that only 3 of 21 subjects verbalized, 2 pointed or reached for the object and 3 smiled in this age group.
Because gaze appears to be the most important type of feedback continuously given for this age group, we have explored this feature in more detail, especially its precise timing with regard to the adult's actions, in order to verify, whether we could find the patterns revealed in the qualitative analysis.
For the calculation, the infants' gazing directions were classified into gaze to relevant position, anticipating gaze, gaze to interaction partner, moving gaze and gaze elsewhere.

The following features were used in the investigation:

- *Eyegaze to Relevant Position*: Defined as the percentage of time of the demonstrated action looking to the right position, which means to the relevant object or hand. In the subactions a1, a2, and a3, this is always the cup which is being transported. During the time intervals in between subactions, when no cup is transported, but the hand reaches for the next cup, p1 and p2, the right position is considered the hand performing the next action.
- *Eyegaze Anticipating*: Percentage of time of the demonstrated action spent anticipating, that means looking at the goal position of the cup or hand. In subactions a1, a2, and a3, this is the cup, into which the cup which is currently transported will be stacked. In p1 and p2 this is one of the remaining cups, which could be transported next and to which the hand is being moved.
- *Eyegaze to Interaction Partner*: Percentage of time of the demonstrated action spent gazing at the interaction partner. At all time of the demonstration this is the case, when the child is looking at the face of the parent.
- *Moving Eyegaze*: Percentage of time of the demonstration, when eye gaze is shifting or in the process of moving.
- *Eyegaze Elsewhere*: Percentage of time of the demonstration spent gazing anywhere else than the directions above.

Figure 4 shows the results of the gaze features for all age groups. When assessing how much children in group 1 anticipate future actions with their gaze, we measured the mean percentage of time, a child in this age group anticipates a goal by shifting the eye gaze early in direction of the goal position. The results reveal that the percentage of *Eyegaze Anticipating* a next action averages only 13.21% for group 1, whereas they *gaze Elsewhere* 22.83% of the demonstration. To measure the amount of attention grabbing patterns, we first parsed the parents' utterances annotated in the praat textgrids for the term "guck mal', which is German for "look" and then, focused on the gazing direction of the child right at the beginning of the utterance of the signal using the time stamp of the utterance obtained from the textgrid. The computation

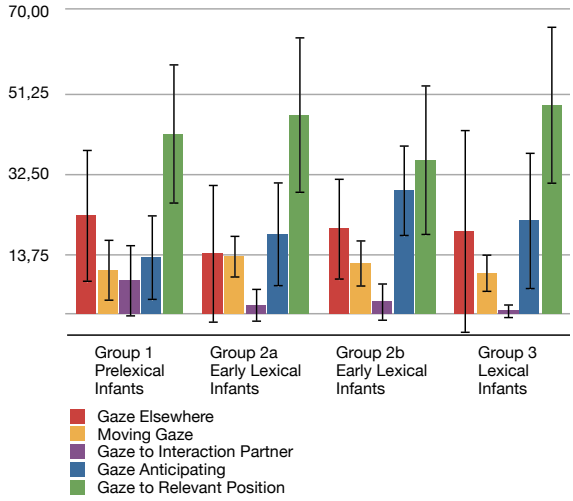

Fig. 4. Graphic depicting the percentages of the demonstration the child gazes in the different directions with standard deviations.

shows that 13 of 23 times the term was uttered, the child looked to a position which was not relevant at that particular moment. Additionally, we were curious about where children who did not look to a relevant position before the attention grabbing pattern would look after the term was uttered by their parents. We found that out of the 13 children who did not gaze to the relevant direction, 9 shifted their gaze either to the objects (5) or the parent's face (4) within 2 seconds after the attention grabber. The rest of the children all except for one, shifted gaze to a more relevant position, such as the hand of the parent or the plate supporting the objects. These findings suggest that "guck mal" is often used as an attention getter in this age group which seems to effectively orient the children's attention towards a relevant position.

C. Group 2: Early Lexical Infants (12 to 24 months)

1) Qualitative Analysis: For the interaction with early lexical infants, we find that (a) some children continue to exhibit the "observer feedback" revealed for group 1, while (b) other infants begin to respond differently to the actions presented. In what follows, we will begin to reveal these new features and issues exhibited by group (b) with the help of a qualitative case analysis.
(i) When new objects are placed on the table, infants tend to orient to them by themselves and claim physical access. In the following example, the child RC acknowledges the arrival of the objects verbally (figure 5, l.01: "tiTI, (.) daDA:;") and gazes at the cups while the experimenter explains the task to VP (figure 5, l.02). Once VP touches the first (green) cup, the infant immediately requests the object by both reaching towards it (figure 5, img.1) and yelling "MAMA::? MAMA::;!".
(ii) This infant's initial pro-active reaction towards the objects is interesting as well as it creates a different starting situation, in which the parent's presentation takes place. As the infant is already oriented to the object, the adult's "attention grabbing" actions as shown for group 1 would not be required. However, interestingly parents still use the same communicational

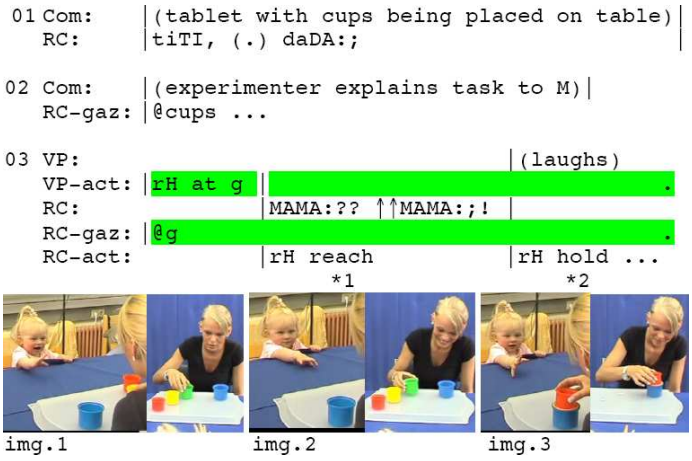

Fig. 5.

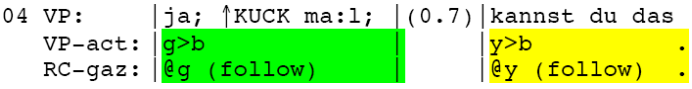

Fig. 6.

devices - such as "LOOK" - at the onset of their action presentation (figure 6, l.04 "KUCK mal").

As the child is already gazing at the appropriate place (figure 5, 6, l.03-04: "@g"), no change in the infant's orientation occurs. Thus, "attention getters" - although produced by the parents in both groups - now begin to change their interactional functions: They assume the role of "structuring signals" which mark the beginning of the action demonstration.

(iii) While in group 1, the infant's gaze continuously follows the parent's action presentation, in group 2, we find infants more importantly anticipating next actions in the series of sub-actions. In our fragment, RC directs her gaze already to the third (red) cup while VP still finalizes dropping the yellow cup into the blue one (figure 7, l.05).

(iv) Not only does the infant's anticipating gaze visibly display (both to the adult and the researcher) an understanding of the action and its serial character, but also do other forms of feedback provide further insights into the child's cognitive processing capabilities. In our example, the infant requests the cups at the onset of the demonstration verbally and by reaching (see above (i), figure 5, img.1), then rests her - still extended arm - on the table (figure 5, l.03, img.2). Interestingly, her arm "freezes" in this posture during the entire action presentation and once the last (red) cup drops into the blue one, RC again reaches towards the cup and yells "MAma; MAMA:::!" (figure 5, l.06, img.3). Thus, the infant displays an understanding also of the expectable end of the demonstration and that the object

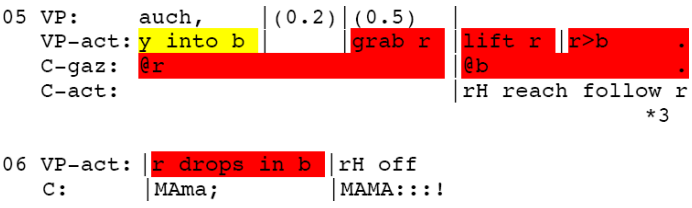

Fig. 7.

Fig. 8.

is again "requestable" for her.

2) Quantitative Analysis: Quantitative Analysis shows that in this second group, 11 of 23 children verbalize during the demonstrations, 8 of them point or reach and 5 of them smile. This suggests a much more active feedback behavior in speech and movement.

Compared to group 1, the infants of subgroup 2b anticipate significantly longer (Mann-Whitney U test, $***p < 0.001$).

The findings of the qualitative analysis suggest that infants in this age group should more often look at the right cup before the parent utters "kuck mal" than gazing at irrelevant positions, because this would confirm the change of use of the term towards a structuring signal. Indeed, this is the case for 7 out of 9 times the term was uttered.

D. Group 3: Lexical Infants (25 to 30 months)

1) Qualitative Analysis: In group 3, lexical infants, some parents begin to redefine the task of mere action presentation by more actively requesting the infant's feedback, e.g. through tag-questions, delaying actions or asking "do you know which color this is?". In addition to the still remaining "observer feedback" from group 1, the infant's feedback thus becomes more elaborated. While appropriate gaze behavior remains an important feature, examples show that infants not only display their understanding of sub-actions, relevant next actions and the action as a whole, but also begin to translate this understanding into suggestions/instructions for the demonstrating adult located at precise moments in time. As an example, consider the following fragment, in which the infant (i) firstly observes the adult placing the red cup into the yellow one and then (ii) points for each new subaction towards the goal/cup where it is supposed to be placed. So, the infant points to the red/yellow cup at the end of the first stacking action (figure 8, img.1), then gestures over to the green cup, i.e. the goal of the next stacking action (figure 8, img.2). Similarly, she gesturally anticipates and directs the next stacking action, i.e. the green cup into the blue one (figure 8, img.3). Only at the end of the adult performing this last action, the infant changes her hand shape attempting to grab the cups (figure 8, img.4).

When providing such "action guides" to the demonstrator, the infant's timing of its own (verbal and bodily) action in relation to the adult's presentation appears to be highly systematic: (i) after the first sub-action and (ii) at the end of the second and third sub-action - thus anticipating rather early the next action.

2) Quantitative Analysis: To substantiate the advanced systematicness of the infant's feedback in this group, we tried to find a measure which shows that the infant's feedback follows the structure of the action. For each kind of feedback, we considered for the other age groups, we took the time

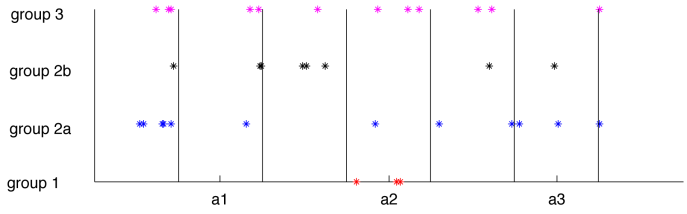

Fig. 9. Interval starts of pointing and reaching gestures for the different age groups.

stamp of the beginning of the respective feedback intervals and computed the distance to the nearest action boundary from the ELAN files, see figure 1. Unfortunately, we did not find any meaningful results. Even when scaling the action parts to all have unity length and visualizing the beginnings of feedback intervals, we do not see regularities, see figure 9.

VI. Discussion

Our analysis has shown that infants provide different kinds of feedback in the three age groups. Also, close inspection has revealed that the infants' feedback operates on two levels: as continuous involvement (e.g. through gaze) and at specific places within the structure of the interaction (e.g. through pointing gestures at objects). Even though the age distinctions between group 1 through 3 are small, the results reveal noticeable differences in feedback: In group 1, feedback consists primarily of gazing behavior displaying the infant's state of attention. In group 2, children begin to anticipate next actions with the direction of gaze and use more gestures and other modalities as feedback with which they provide the parent with information about the understanding of the presented action. This becomes even more evident in the feedback of the children in group 3 who give feedback much more systematically according to the structure of the action. We suggest that feedback has to be considered in relation to the interaction partner's current actions. In our analysis, we have undertaken a first attempt to investigate such links between the infant's feedback and the parent's presentation. Our analysis has revealed two central interactional patterns which take this interrelationship into account: (1) Considering the precise timing of the infant's gaze in relation to the adult's hand movements, we found that the infant's gaze *follows* current actions or *anticipates* the next relevant action. The latter is mostly the case for the children of the early lexical and lexical groups 2 and 3. (2) Considering the precise timing of the infant's gaze in relation to the adult's verbal utterance "look"/"kuck mal", we found that its function changes with the infant's age: While it serves to grab the child's attention in group 1, it becomes a structuring signal that marks important points of the demonstration to the children in group 2 and 3. When trying to bring the structure of the action and the children's feedback closer together taking objective action and sub-action boundaries, however, we fail due to the variability of human interactional conduct. While the moments in time at which an infant provides feedback are highly systematic for the child in each single case, once we attempt to detect these over the corpus, we run into problems. From this we draw that more advanced methods and more precise patterns of features drawn from concrete hypotheses generated by qualitative analyses are required to link the infant's feedback to the adult's actions - given the complexity and variability of human social conduct.

From this work, we can derive the following implications for the development of robot systems that should learn from a tutor in social interaction: The feedback a robot should give should be twofold. It should provide a continuous part and a part transmitted at specific moments in time making use of multimodal conduct and thus, making it possible for the robot to influence the presenter's actions.

Next steps will consist in continuing to link closely the adult's presentation and the infant's feedback in order to reveal more patterns of the "interactional loop'. We will need to identify the precise moments at which feedback is generated and take into account not only the structure of the action presentation, but include more systematically social cues, such as the tutor's gaze.

Acknowledgment

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